POROSITY AND PERMEABILITY

Purpose:

This lesson will give students an opportunity to measure and calculate the porosity and permeability of a rock sample. Students will also be able to demonstrate the effect of grain size on porosity and permeability.

Concepts:

1. Permeability and porosity are related characteristics of rocks.
2. Permeability and porosity are related to the size, number, and interconnectedness of openings in a rock.

Duration of Lesson:

Two 50-minute class periods

Objectives:

As a result of participation in the activities entitled *Porosity and Permeability* (experiment), *Porosity* (worksheet), and *Permeability* (worksheet), the learner will be able to:

1. identify factors affecting permeability and porosity;
2. calculate percent porosity given total volume and volume of open space;
3. calculate surface area; and
4. relate surface area to permeability.

Skills:

Analyzing, calculating, drawing conclusions, hypothesizing, measuring, observing, recording data, working in groups

Vocabulary:

Permeability, porosity, sediment

Materials:

Activity Sheets

Porosity and Permeability, p. 183
Porosity, p. 187
Permeability, p. 189

<u>Videotape</u>

Science, Society, and America's Nuclear Waste Teleconference Videotapes **(available free of charge from the OCRWM National Information Center, 1-800-255-6972; within Washington, DC, 202-488-6720)**

Other

1-liter soda bottle	stopwatch	plastic tubing - short length
1 graduated cylinder (1-liter) or other liquid measure	clean sand	glass tubing - short length
	rubber bands	pinch clamp
marbles (uniform size, not too large)	copper shot (BB's)	rubber stopper with hole
cheesecloth		

Suggested Procedure:

1. The relationship between porosity and permeability is often difficult to understand without some sort of demonstration. It is difficult for anyone to understand that two sediments composed of different grain-sized materials can have very similar porosities and yet very different permeabilities. The purpose of this activity is to make the students think about the relationship of porosity and permeability in analyzing the results of the experiments.

2. The total volume of the sediment is an approximate calculation assuming the funnel approximates a cylinder and the non-cylindrical parts are insignificant. You may want to treat the non-cylindrical part as half of a sphere to get a more accurate volume calculation. It may make for an interesting discussion to compare the assumptions and acceptable errors in these approximations.

3. The porosity of a sediment composed of spherical particles depends on the packing of those particles. In their closest packing arrangement, the porosity will be approximately 27%. In a more open packing the porosity may approach 45-50%. In the experiment the bulk of the particles will naturally move into a closest-packed arrangement. However, near the walls of the funnel this arrangement is disrupted and this disruption is more pronounced with larger grain sizes. Therefore, the porosity will vary with grain size in this experiment because of the "wall effects." However, as grain size decreases, the wall effects on packing diminish and measured porosity will approach the theoretical closest-packing porosity.

4. The measure for permeability used in this experiment is very simplistic but adequate for the purpose of illustration. It is critical that the flow rate be measured using the same initial volume for all three sediments to allow valid comparisons. The weight of overlying water in the sediment forces water out. As the amount of overlying water decreases during the experiment, the flow rate in this apparatus will decrease. The suggested range of volume (50-100 mL) may be too large. Use smaller, convenient volumes at your discretion.

5. The percentage of total porosity volume recovered will also vary with the grain size. As grain size decreases, the surface area increases and pore size decreases. The water that is not recovered in a reasonable amount of time is water attached to surfaces, physically sorbed, and trapped in small pores and pore openings. It is important to mention that this water does not move under normal conditions and, although it went into determining the total porosity of the sediment, it is not part of the effective porosity.

6. Before students begin the experiment entitled *Porosity and Permeability,* it may be helpful to discuss the general concepts of permeability and porosity. The following suggested discussion questions may help students understand the purpose of this experiment, and formulate educated hypotheses.

Suggested Discussion Questions:

1. Explain porosity.

   (Students should mention that porosity is the open space in a material that could be filled by a fluid. Students may think of fluids only as liquids. You may want to remind them that air is also a fluid.)

2. Can you think of an example of something porous that is not a rock?

   (A building is porous, rooms act as pores, bread has air pockets, a sponge, etc.)

3. Explain permeability.

   (Permeability is a measure of the ease of flow of a fluid through a material.)

4. Can you think of an example of a permeable substance that is not a rock?

   (A building is also permeable, halls connect rooms, the air pockets in bread may be connected like tunnels, etc.)

Once students seem to understand and transfer the concepts of porosity and permeability, have them read through the experiment independently.

It may be necessary to ask students procedural questions to ensure that they understand what they will do.

5. What variable(s) will be changing during this experiment: water volume, sediment volume, and/or grain size?

   (Grain size.)

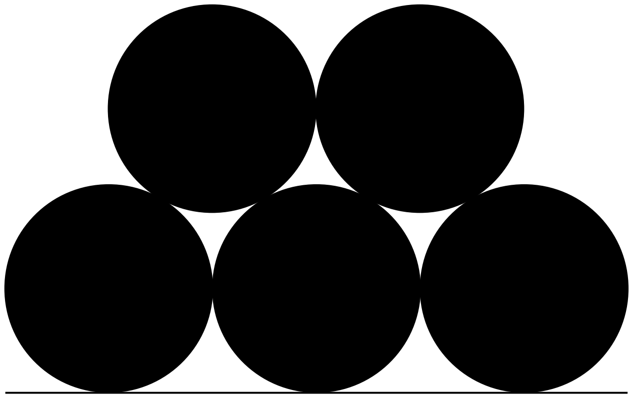
6. How do you think porosity relates to the grain size of a sample?

   (Students will probably say that increasing grain sizes will increase porosity, but this is not true in an actual measure of porosity. In a sample of spherical particles all the same size, the porosity is not related to the size of the particles making up the sample. Porosity depends on the packing of those particles.)

To ensure that students understand that porosity is not related to grain size if the grains in a sample are spherical and the same size, as in this experiment, but rather to the packing of those grains, it may be helpful to use the following demonstration.

a. Use approximately six large spherical objects such as basketballs and six smaller spherical objects, tennis balls perhaps.

b. Stack both sized objects in their closest packing arrangement as illustrated on page 38. Have students leave their seats to examine the amount of pore space left open in each set of spheres.



Closest packing arrangement

c. Encourage students to compare the amount of pore space they observed to the total volume of the stacked spheres to determine a relative porosity for each stack. Ask what percent would be left open as pore space if the stack represented the entire volume of rock.

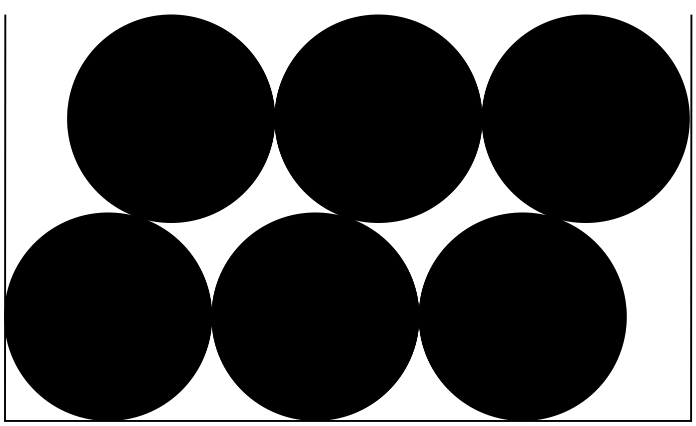
(Students should estimate a similar percent of pore space for each set of spheres.)

i. If each stack represented a rock, and each sphere a grain in that rock, how would you describe that rock?

(All grains are the same in each separate rock, all grains are spherical in shape.)

ii. Do you think that, if these were rocks, porosity would be different between the two?
(No, it wouldn't be.)

d. In this experiment, the bulk of the particles will naturally move into a closest packed arrangement. However, near the walls of the funnel this arrangement is disrupted. This disruption is more pronounced with larger grain sizes. Therefore,the porosity will vary with grain size in this experiment because of the "wall effects." However, as grain size decreases, the wall effects on packing diminish and measured porosity will approach the theoretical closest-packing arrangement.



Wall effects disrupt closest packing arrangement

e. You can demonstrate wall effects using two boxes. One box should be large enough to disrupt the packing of the large spheres and the smaller box should do the same for the smaller spheres. See diagram below.

f. Put each size sphere in the appropriate box and have students compare the amount of pore space available to the total volume of the boxes for each grain size. Have students observe where and how the closest packing arrangement is disrupted by the sides of the box.

(Students should recognize that pore spaces increase due to wall effects as grain size increases.)

7. State a rule relating grain size to porosity.

(In a sample of spherical particles all the same size, porosity is not related to grain size but it is related to particle packing.)

8. What role do you expect wall effects to play in this experiment?

(Wall effects may effect porosity in this experiment. They will be most pronounced in the larger grain-sized samples.)

9. How will you measure the porosity for each grain size?

(The volume of water needed to just cover the top layer of sediment will equal the volume of pore space in each sample.)

If students have difficulty with this question, remind them of this procedural step and ask them where the water goes.

10. In this experiment, will permeability be affected by grain size?

(Yes. As grain size increases, pore spaces will be larger and allow easier water flow. In addition, porosity will increase with grain size due to wall effects and, thus, permeability will increase.)

11. How will you measure permeability for each grain size?

(Rate of flow will be a measure of permeability. The greater the flow rate, the greater the permeability.)

7. Allow students time to write the purpose of the experiment and their hypotheses regarding the outcome. Then take a short time to discuss their answers before allowing activity to begin.

8. Upon completion of this experiment students should complete the activity worksheet entitled *Porosity* and the activity worksheet entitled *Permeability* for homework. These activities involve simple mathematical calculations that will serve to reinforce the concepts stressed in the

discussion and the experiment. The porosity activity worksheet will give students practice at calculating percent porosity for several rock types. The permeability activity worksheet illustrates the relationship between grain size and surface area.

Teacher Evaluation of Learner Performance:

Student participation in experiment/activity and completion of related activity sheets will indicate understanding.